COMBUSTION

OTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

July, 1945

Power and Chemical Recovery for a Southern paper mill

Tube Failures in High-Pressure Water-Tube Boilers ▶

Storage of Coal ▶

America's Future Oil Supplies ▶

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ALFRED D. BLAKE, *Editor* — THOMAS E. HANLEY, *Circulation Manager*

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Editorial

Combating Increased Production Costs

Of practically all the essential commodities, electricity alone has not advanced in price to the consumer. In fact, under regulatory direction, rates have steadily decreased. Yet two major items that enter into production cost, namely fuel and labor, have increased with no prospect of reversion to pre-war levels. Moreover, in many cases, more coal must be burned to produce a given amount of electricity because of the lower heating value and poorer quality of much that is now available.

The large modern power station has about reached the limit of its optimum heat rate with the present steam cycle and there is no immediate prospect of employment of a more efficient cycle. Of course, there are many plants, both central station and industrial, that are far from attaining the best performance, due to obsolete or physically depreciated equipment; and herein lies the opportunity of raising the average level of performance.

Aside from this, the differential between allowable rates and increased production costs can be assisted by greater output and improved load factor, which will tend to decrease proportionate fixed charges, overhead and distribution costs. That this will be possible is indicated by the trend toward continued increase in output by utilities during the next twelve months and the likelihood that pent-up demand for goods will result in still greater demand for electric energy, both purchased and privately generated, during the post-war period.

However, few people appreciate the technological effort that has gone into making electricity, the greatest servant of mankind, available to practically everyone at a cost incomparably lower than most commodities.

Information on Research

Battelle Memorial Institute, Columbus, O., was founded a little more than fifteen years ago with the two-fold purpose of providing research for industry on a non-profit basis, and, through its endowment, to carry on fundamental and applied research aimed at advancement in technology. Unlike many other research bodies, it has depended upon the technical press for dissemination of the results of the latter function in the fields of chemistry, ceramics, metallurgy, industrial physics, fuels and mechanical engineering.

As a convenient reference, rather than making it necessary to consult the indexes of numerous publications, the Institute has just issued a 72-page catalog of such published articles and patents, involving over eight hundred listings for the years 1929–1944.

During the war period a vast amount of research has been underway at various institutions, much of which, for military reasons, has not yet been released to the engineering public. When the time arrives for its release, the plan long followed by Battelle with reference to the technical press would appear to be the most logical means of benefiting industry, as a wider audience is thus assured than through reports which usually have limited circulation.

TUBE FAILURES IN WATER-TUBE BOILERS

By JOHN VAN BRUNT, Vice Pres.

Combustion Engineering Company

Fifteen general types of water-tube failure are discussed as to appearance and cause. By means of the sketches it should be possible to identify readily the probable cause of any such tube failure.

BOILER tubes may fail in service from various causes. With each type of failure there are certain physical characteristics which are peculiar to that particular type of failure and which, in practically every case, will definitely identify the cause.

A boiler tube fails because of some condition that weakens the metal to such an extent that it cannot withstand the stress due to internal pressure or other stress to which the tube may be subjected. As above stated, the nature of the fracture, the size and shape of the opening, and the appearance of the edges, as well as the condition of the internal surface, will usually give evidence of the cause.

Boiler tube failures may be divided into fifteen general types or classes as follows:

1. Defective tubes
2. Rapid overheating.
3. Prolonged overheating involving creep rate.
4. Corrosion, internal due to acid.
5. Corrosion, external due to low temperature (condensation).
6. Corrosion, external due to slag attack.
7. Corrosion, internal due to oxygen or CO_2 pitting.
8. Corrosion, internal in partly dry tubes.
9. Corrosion under scale, sludge or corrosion products.
10. Corrosion-fatigue.
11. Internal cracking.
12. External cracking.
13. Erosion, external from fly ash or cinder.
14. Fatigue.
15. Caustic embrittlement.

Some of these classifications overlap, as 2 and 3, where, while the ultimate failure is the same, the basic cause may be different. Classes 10, 11 and 12 are also similar.

Defective Tubes

Defective tubes that may fail in service are of four types, namely, (1) laminations or folds in the tube wall, (2) dirty metal slag or other non-metallic inclusions, (3) improperly heat-treated tubes, and (4) tubes with eccentric bore. Of these defects the last named is rare and inspection will eliminate practically all such tubes except the very unusual case in which the eccentricity occurs in the middle of the tube but does not show at the ends.

Failure occurs because the thinned metal will not stand the internal pressure. Examination of the margins of opening coupled with the obvious variation in wall thickness will positively identify the cause of failure. Fig. 1 illustrates a failure of this kind.

If the tube is not overheated the perimeter (p) will be but little greater than the normal tube perimeter, the elongation at the edges will be slight and the edges (e) of the break will have the appearance of a specimen broken in tension.

Folds or Inside Laps

Folds or laminations usually occur at one end of a tube and result from a tear in the metal when the billet is pierced. Such tearing is not likely to occur if the metal is free from non-metallic inclusions and porosity. Usually inspection will reject all such tubes, but occasionally one will slip through.

Fig. 2 shows a failure due to a fold starting at the inside wall of a tube at (a). Such a fold may extend far enough into the metal to greatly weaken the tube. At the sharp end of the fold concentration of stress will cause progressive deepening of the lap until the remaining solid metal will not withstand the internal pressure. The edges (e) of the fracture will be ragged and the surfaces (c and d) will show that the metal was not continuous because of the fold that existed. The perimeter (p) will be little if any greater than the normal tube circumference.

Slag Inclusions

Failure due to slag or other non-metallic inclusions may be identified by the nature of the fracture and.

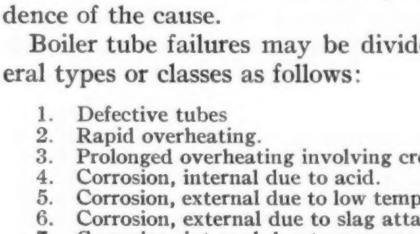


Fig. 1—Fracture in an eccentric tube

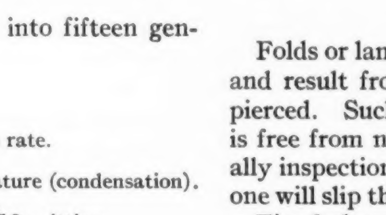


Fig. 2—Fracture of tube with inside fold

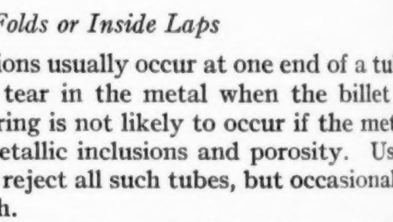


Fig. 3—Slag inclusions and nature of fracture

though relatively rare, there have been enough cases to warrant discussion. Generally, such inclusions are small and can only be found by microscopic examination. If they are grouped as indicated at (*a*) in Fig. 3, and extend for several inches along the tube, failure may result. The fracture will be ragged with no reduction in area as at (*b*).

Inclusions as at (*c*) and (*d*) are rare but have been observed. Where the area is large or over an inch in diameter, if located as at (*c*) the metal outside of the inclusion will overheat, blister and burn off. If the remaining metal is thick enough to hold the pressure, failure is not probable. An inclusion of the same area close to the inside wall, as at (*d*), will retard heat flow and cause overheating of the metal outside of the inclusion.

If the tube is subject to very high temperature the metal will be so weakened that the metal inside of the inclusion will fail. The fracture will exhibit little elongation and have the appearance of a tensile test specimen. Non-metallic inclusions of small areas, as at (*e*), which lie parallel to the tube surface are not likely to cause failure.

Improper Heat Treatment

Tubes may be too hard or too soft, or may lack impact resistance because of improper heat treatment. For satisfactory rolled joints, they should be soft, compared with the drums or headers into which they are rolled. If too hard, tight rolled joints are difficult if not impossible to obtain. Leaks in a rolled joint, if not located soon enough, will cut the tube seat and perhaps adjacent tubes.

Tubes may be too soft and lack ductility, in which case they may fail in bending or rolling, or due to rough handling. If such a tube is put in service, failure from circumferential cracking is probable. Such cracks will usually occur at a point where there is a bending stress. The fracture will be rough with no elongation and will have a coarse grain structure.

Short-Time or Rapid Overheating

Failures from rapid overheating have the same appearance as those due to prolonged overheating; the cause, however, is usually different. Tubes failing from rapid overheating are likely to reach a higher temperature than those subjected to prolonged overheating, because of the conditions that produce the overheating.

Rapid overheating may occur in a clean tube and is due to lack of water on the evaporating surface for a period only sufficient to allow the metal to reach a temperature above 1400 F.

The usual causes are low water in the boiler or an obstruction in the tube which reduces the flow so that there is no water or a very small amount at the point of failure. Obstructions may be deposits of scale or sludge and scale, tools or gloves, caps, or other like material carelessly left in a tube end by workmen. If such an obstruction limits the flow of water to an amount that would be evaporated in the lower half or two-thirds of the tube, the upper half or one-third would be cooled only by steam at low velocity, and such cooling would be insufficient to protect the tube.

Unless such an obstruction is firmly wedged in the end of the tube it will be blown out when the tube bursts, leaving no evidence of the cause. Scale and sludge deposits in the ends of adjacent tubes may be sufficient to indicate the cause. Fig. 4 illustrates this condition.

There is a case on record of a failed tube where there was no direct evidence of an obstruction but when an internal examination of the boiler was made several wood blocks were found of a size that could enter the end of a tube. It was assumed, in the absence of any other logical explanation, that one of these blocks jammed in the tube end and was blown out when the tube failed.

Low Water

Low water is the other principal cause of rapid overheating and, as in the case of a foreign obstruction described, the tube may be clean and free from scale or sludge.

Failures from low water are immediately preceded by a rise in superheat temperature of 50 to 100 deg, occurring in a few minutes. The period of overheating coincides with the steam temperature rise. In a boiler without a superheater there is no other indication until failure occurs.

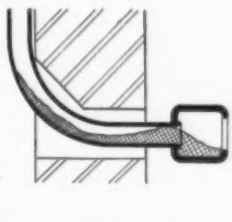


Fig. 4—Sludge deposit in tube end

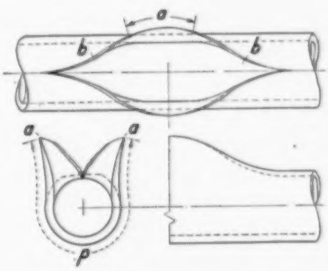


Fig. 5—Fracture of overheated tube

The appearance of the fracture will be the same whether the cause is low water or obstructed circulation. The cause may be identified by the appearance of adjacent tubes. If low water is the cause, adjacent tubes also show definite signs of overheating, such as stretching or increased diameter or warping, and may have bulges at or near the elevation of the failure. A steam-temperature recording chart may be said to furnish the necessary written evidence to prove the cause.

The fracture will be much as shown in Fig. 5. The edges at (*a*) will be sharp, almost drawn to a knife edge, while at (*b*) the edges of the tear will be thicker. The perimeter (*p*) will be considerably more than the normal tube circumference. In a water-wall tube the stretch will be almost entirely in the furnace half of the circumference, while in a boiler tube, surrounded by hot gas, the stretch may include the entire circumference. Due to the reaction of the steam and water leaving the break, the tube will be bent away from the break.

In a two- or three-drum, bent-tube boiler, with a high water-cooled furnace, the bottom of which is ten or more feet below the lower drum, the tubes in the front row are most likely to fail in the event of low water.

Slow or Prolonged Overheating

This type of overheating may be due to either a coating of scale or sludge on the inside of the tube, or to a sensitive circulation where the tube receives very little

heat on the bottom portion and a large amount at the top. Under these conditions the mean density of the mixture will be high, the head low, and the proportion of steam at the upper end of the tube will be very high.

Scale or sludge on the inside prevents the water from making contact with the metal, which causes increased metal temperature. As the scale thickness increases the tube temperature also increases. Depending on the conductivity of scale and the rate of deposition, the tube may reach a temperature well within the creep range in a few months.

The fracture will be much as shown in Fig. 5 with a considerable increase in perimeter at the point of fracture and a material increase in diameter above and below the fracture. The failed tube will usually be cleaned of scale by the rush of water and steam when failure occurs. In the absence of scale in the failed tube the condition of adjacent tubes will serve to identify the cause. Adjacent tubes will usually be coated with scale, show signs of overheating, increased diameter and sometimes bulges in the tube wall at the elevation of the fracture.

Another kind of slow overheating may be found in tubes where, under certain conditions, less heat is absorbed by one portion of the tube than by another. This tends to reduce circulation and the proportion of steam to water in the top of the tube becomes high. The metal temperature may reach 1100 to 1300 F.

These temperatures are in the creep temperature range; that is, at these temperatures the strength of the metal is so reduced that a slow elongation or stretching occurs. As the tube wall becomes thinner stress increases and the rate of stretch also increases until the tube bursts.

Tables 1[1] and 2[1] show the short time tensile properties of steel from 1000 to 1400 F and the creep rate from 1000 to 1200 F.

A 3-in. tube with a 0.26-in. wall in a boiler operating at 1350 psi would be stressed to about 6400 psi. This is 60 per cent higher than the stress of 3850, at 1100° F, which results in a creep of 1 per cent in 1000 hr.

If the temperature and stress is such that the creep rate is 1 per cent in 100 hr, in 830 hr the tube will stretch $^1/_4$ in. to $3^1/_4$ in. diameter. At this diameter the stress will increase to about 7100 psi, thereby further increasing the creep rate until failure occurs. At a temperature of 1200 F the rate of creep will be much higher and failure will occur in a shorter time. The fracture will be much the same as in Fig. 5 except that the edges will not be as sharp as in the case of a rapidly overheated tube.

TABLE 1—KILLED CARBON STEEL

C.0.10–0.20 Manganese 0.30–0.60 Phos. 0.04 Max S. 0.045 Sil. 0.21

Temp.	Ultimate Strength	Yield Strength	Proportional Limit	Elongation	Reduction of Area
1000	36,500	20,100	8750	42.5	76.9
1100	27,200	14,250	5000	56.5	82.2
1200	20,000	10,200	1875	54.5	89.1
1300	13,000	7,375	0	59.5	91.6
1400	9,025	3,750	0	69.5	76.9

TABLE 2—CREEP STRENGTH

	Creep Rate		
Temp.	1% in 100,000 Hr.	1% in 10,000 Hr.	1% in 1000 Hr.
1000	2700	5750	12,100
1100	840	1800	3,850
1200	290	620	1,300

[1] Taken from "Digest of Steels for High Temperature" by the Timken Steel Tubes Company.

Acid Corrosion

Internal corrosion due to acid is rare and occurs only when the boiler feedwater is contaminated by water from processes that are acid or which becomes acid by reactions within the boiler. Corrosion will be severe when metal is highly stressed, such as rolled tube ends.

External corrosion at low temperature is more common in economizers and air preheaters than in boilers. When the metal temperature is lower than the dewpoint of the products of combustion, condensation takes place. Sulphur present as SO_2 or soluble sulphates in the dust combines with the moisture and forms sulphuric acid. The dewpoint of the flue gas depends on moisture and sulphur in the fuel and the end-products of its combustion. With a high-sulphur oil, a dewpoint as high as 360 F has been observed.

Corrosion of boiler tubes from this cause is unusual except where feedwater temperature is very low and the water is introduced into the boiler in such a way that some of the tubes have a temperature lower than the dewpoint of the gas.

When a boiler is shut down for protracted periods, condensation of moisture on the tubes will flow down the tubes to the lower drum, causing acid attack on the drum and tubes.

External Corrosion from Slag

This type of corrosion is of comparatively recent origin. For a complete description of this form of attack see papers by B. J. Cross, R. C. Corey and W. T. Reid, "External Corrosion of Furnace-Wall Tubes—I and II," in the A.S.M.E. *Transactions*, May, 1945.

Slag attack or corrosion has been found on furnace-wall tubes of slagging bottom furnaces, in some limited areas of horizontally fired, dry-bottom furnaces where intense flame impingement on furnace walls keeps the slag fluid, and on radiant superheaters. From a practical standpoint the mechanism is somewhat as follows:

Normal oxide scale on the surface of the tube is progressively removed by chemical action of fluid slag and by mechanical action of slag which freezes to the oxide and breaks away when cooling, taking oxide scale with it. Fresh steel surfaces so exposed rapidly oxidize, and the process of removal is repeated. This type of corrosion can be readily identified by the appearance of the tube.

Fig. 6 shows the flattening of the tube or wasting of metal. Failure occurs when the tube wall is so thinned that it will no longer hold the internal pressure. The fracture will usually be a longitudinal crack with rough edges and little elongation as at (*a*).

Identification is easy. It involves rough appearance of the tube, a thinned wall, and the condition of adjacent tubes with slag always present, usually quite thin and with definite evidence of flow. Surface under the slag is rough, having the appearance of badly scaled metal. There are usually noticeable patches of an enamel of a green, blue or yellow tint. If the tube is cleaned there will be a flattened area as described.

Internal Corrosion

Internal corrosion may be divided into two types, that due to free O_2 or CO_2 and that due to direct attack of water or steam on the metal.

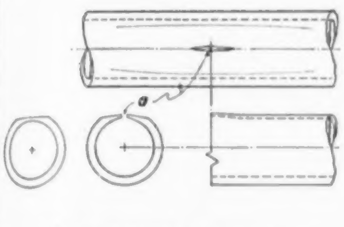


Fig. 6—External corrosion due to slag attack

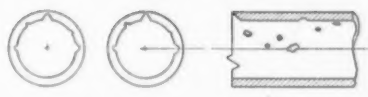


Fig. 7—Example of oxygen pitting

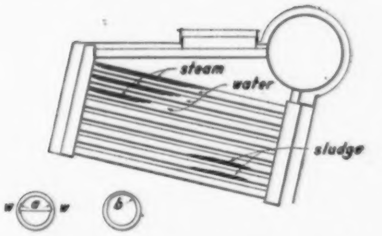


Fig. 8—Corrosion in partly dry tubes and due to sludge deposits

Oxygen corrosion usually occurs as small pits in the tubes or drums. Its occurrence is spotty and it is often difficult to explain why the attack takes place where it does. At low pressures boilers can tolerate some oxygen but as pressure and temperature go up it becomes more and more necessary to eliminate any trace of oxygen. Oxygen may attack either boiler or furnace tubes and under some conditions the corrosion products, if not removed, may insulate the tube and extend the area of corrosion in a manner described later.

Where there is internal corrosion in tubes that are not partially dry, oxygen should be suspected and every precaution taken to insure oxygen-free feedwater. Failures are usually deep pits which penetrate the tube wall, the holes being very small, as in Fig. 7. Examination of the inside of the tube will suffice for identification of the cause.

Corrosion in partly dry tubes or in dry areas sometimes occurs in the upper rows of horizontal water-tube boilers, roof tubes of furnaces, and other tubes which are nearly horizontal and are exposed on the top side to high rates of heat input and where for some reason circulation is slow.

In Fig. 8 the shaded area indicates the location of steam pockets, and the enlarged sections of tubes the corrosion attack in a horizontal water-tube boiler.

In this type of boiler there is recirculation of water in the top tubes; that is, water flows downward in the upper rows while steam is rising. As velocity of both steam and water is comparatively low there is a definite line of demarcation on the tube wall. The top of the tube is swept by steam only while water flows along the bottom. Usually gas temperature at this point is not much over 900 to 1000 F, depending on the number of tubes in the bank and rate of steaming.

In high-pressure boilers of this type there may be only four or five rows of tubes below a superheater. In such units temperature of the gas passing the top tube may be 1800 to 2000 F. Whatever the gas temperature, if the temperature of the top of the tube is materially above that of the steam, there will be a direct attack of steam on metal with the formation of magnetic oxide and a more or less rapid loss of metal from the upper half of the tube; see Fig. 8 at (*b*). At times the corrosion attack will be at the apparent water line *w–w* in the tube, as shown at *a* in Fig. 8.

Examination of other types of boilers and furnaces will disclose locations where the described conditions may exist.

Failure occurs from the thinning of the tube wall and the cause may be identified by the appearance of the inside of the tube. There will be little if any elongation at the failure and the edges will be rough.

Corrosion under Scale or Sludge

This form of attack may occur in vertical furnace-wall tubes although it is more likely to be found in lower rows of horizontal tube boilers or in the second to fourth rows of bent-tube boilers; see Figs. 8 and 9.

Due to the low water velocity at the points illustrated, sludge or scale particles in suspension may settle out on the lower half of the tube wall forming a porous coating which permits some water to reach the tube surface but not enough to keep the inside tube wall temperature at or near saturation temperature. An atmosphere of superheated steam then exists at the metal surface. Metal temperatures of perhaps 100 to 200 deg F above saturation occur and a direct attack of steam on the metal follows. Corrosion products formed further thicken the deposit which again raises the metal temperature and accelerates attack. Sodium hydroxide in the boiler water is concentrated at the metal surface. This also greatly accelerates the corrosion rate. Failure usually is by penetration of the tube wall rather than by overheating. Under some conditions the deposit may be thick enough so that at very high rates of heat absorption the tube may bulge from overheating, in which case edges of the fracture may not be drawn to a knife-edge as in the case of the overheated tube previously described but will be rough and of appreciable thickness. Loss of metal at point of failure will identify the cause as corrosion.

Fig. 10 shows three stages of the progress of corrosion. In stage 1 is a deposit (*a*) of sludge or Fe_3O_4. Stage 2 shows where corrosion has taken some of the tube metal (*b*) and the corrosion products go to increase the thickness of the insulating deposit. Stage 3 shows further progress which continues until failure. When this type of corrosion occurs in vertical furnace-wall tubes the mechanism is the same. It may be difficult to explain how the corrosion starts in a vertical tube except from an initial deposit of sludge or oxygen attack.

Internal Cracking

Another cause of failure is internal cracking, sometimes described as fatigue corrosion. This is due to alternate overheating and cooling of the inside wall of the tube. It may occur in either vertical or inclined tubes but is more probable in tubes that approach horizontal in which the flow is non-turbulent.

Any condition that permits or causes alternate heating and cooling of the inside surface of a tube through a range of 150 deg is likely to cause cracking. While the cracking usually occurs on the bottom of the tube it may also appear on the top surface. Failure results from many abrupt applications of excessive stress due to quick cooling of the metal.

If for any reason a tube becomes dry on either top or bottom and the temperature of the inside wall increases

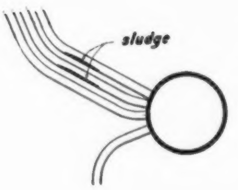


Fig. 9—Location of corrosion due to sludge deposits

150 deg F above saturation, a sudden cooling due to flow of water over the dry area will produce a stress of such magnitude that when repeated many times it will cause cracking of the inside wall.

This type of cracking may occur in any tube in which part of the tube wall is alternately heated and cooled to the above-mentioned degree.

Fig. 11 (*a*) is a view looking down on the cracked surface, and (*b*) and (*c*) are sections through the wall. At (*d*) an enlarged section through one crack shows that the crack is not sharp at the bottom but rounded. The base of the crack will be filled with corrosion products, hence the term "fatigue corrosion" or "corrosion fatigue."

Opinions may differ, but the writer believes that corrosion follows the cracking. Obviously when a minute crack occurs the fresh metal surfaces will oxidize and the crack will fill with corrosion products. It is possible that this formation of oxides exerts a force tending to increase the depth of crack. Failure occurs because of stress concentration at the base of the crack. The failed tube will show no apparent elongation nor increase in perimeter at point of fracture.

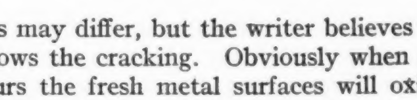


Fig. 10—Progress of corrosion from slag deposits

The failure may be either a short crack through the outside wall, or if the cracking is severe the tube may open for several inches. Whichever the case, the appearance of the inside of the tube is a definite indication of the cause.

The magnitude of the stress imposed under conditions of alternate heating and cooling may be seen from the following example:

Assume a saturation temperature of 500 F and that, because of lack of water, the tube wall reaches a temperature of 700 F on the inside and 750 F on the outside, or a mean wall temperature of 725 F. If the coefficient of linear expansion is 0.000007 the tube will expand 0.000007 $\times$ (725 $-$ 500) = 0.001575 in. per inch. Now if a rush of water at 500 F suddenly cools the inside wall of the tube to 500 F, surface fibers of the metal will shrink instantly to the original length and the steel will be stressed, S = 30,000,000 $\times$ 0.001575 = 47,250 psi. If repeated with sufficient frequency failure is certain.

External Cracking

External cracking of tubes is less frequent than internal cracking. External cracks are called fire cracks and are normally found on headers or drums exposed to heat of the furnace. External cracks on tubes are not common. They are found mostly on heavy-gage tubes and particularly those that are cleaned by lancing with water and air, or water and steam. If the steam line supplying the steam lance is not thoroughly drained, a considerable amount of water may be blown against the tubes that are being cleaned and may cause the rapid cooling which does the damage. Cracking results from rapid or instantaneous cooling of outside fibers of the tube wall through a range of 150 to 200 deg F, or more. Fig. 12 illustrates this type of cracking.

Considering the length (*l*), Fig. 12, of a portion of the face of a tube heated to 150 deg F above the temperature of the inside of the tube, this length cannot increase as the amount of cooler metal in the unexposed portion will prevent longitudinal expansion; hence the hot face of the metal must upset. Circumferential expansion without upsetting can take place to some degree as the tube can distort slightly as indicated by the dotted lines at (*a*).

If the surface is suddenly cooled by the application of sufficient water to lower the temperature of the outside face 200 deg F the upset metal will shrink and the imposed stress may be calculated as previously described.

Circumferential cracks are likely to be deeper than longitudinal cracks as circumferential stress is to some degree reduced by ability of the tube to return to its original circular section. As in the case of internal cracks corrosion products will be found in the cracks.

Temperature changes of less magnitude will mark the surface of the tube in about the same pattern as shown in Fig. 12 but the markings will be very shallow depressions which, over a long time, may develop as cracks.

External Erosion

External erosion may be likened to sand-blasting and may be due to ash particles in the gas moving at high velocity or to action of soot blowers blowing suspended ash against the tubes. Entrained water from soot blowers or leaks in tube seats or economizer joints will also erode tubes or any metal on which such leaks of water impinge.

Erosion from fly ash or cinder usually occurs at points where ash tends to concentrate in the gas stream. Leaks in baffles, eddy currents around U-bolts are also points of erosion. The erosive action of ash may be severe

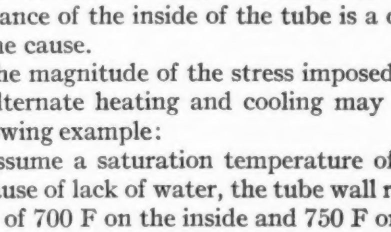


Fig. 11—Internal cracking

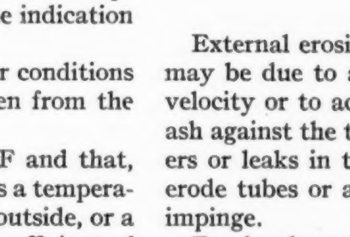


Fig. 12—External cracking

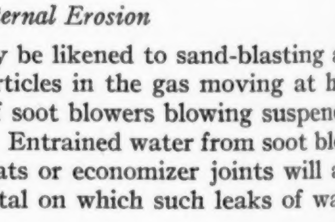


Fig. 13—Caustic embrittlement in tube ends

enough to cut through a boiler tube in a few months.

Erosion may be readily recognized by the polished appearance of the tubes and the characteristic flow lines around the deeper eroded areas.

Fatigue

Failure from fatigue is not common but may occur at places where tubes are subjected to excessive bending stresses because of lack of provision in design or erection for proper expansion. Usually such points of maximum stress are at or near the rolled joints. With heavy wall tubes and deep tube seats severe bending stresses frequently reversed may result in fatigue and failure.

Failures are in circumferential cracks with no elongation. Identification may be made by microscopic examination of grain structure and a careful analysis of possible strains due to expansion.

Intercrystalline Corrosion

Caustic embrittlement, or, more correctly, intercrystalline corrosion, describes a corrosion attack on the grain boundaries of the metal. It is commonly associated with high concentrations of sodium hydroxide at points where the metal is highly stressed and it has been the cause of many disastrous explosions of boilers with riveted drums or shells operating at pressures of 450 psi and below.

Embrittlement cracking of tube ends where they are rolled in drums or headers results from a concentration of caustic salt in any capillary spaces between the tube and tube seat. In Fig. 13, representing a water tube improperly rolled in a tube sheet, there may be a space as at (*a*). Water fills this space and evaporation builds up a concentration of caustic in this space as at (*b*). The tube being highly stressed in rolling, we have the combinations of high stress and caustic concentration on the tube metal. Circumferential cracks will develop about where indicated.

It has been found in low- and medium-pressure boilers that if a proper ratio of sulphate to carbonate in the boiler water is held embrittlement is inhibited.

Identification of this type of failure is made by microscopic examination of the metal at the crack coupled with a check of the sulphate-carbonate ratio and a test of the boiler water for embrittling characteristics.

If microscopic examination shows that the cracks follow the grain boundaries or are intercrystalline they are caused by intercrystalline corrosion.

Aside from the reference to caustic embrittlement, the experience from which this material was prepared is largely based on boilers of 900 to 1500 psi operating pressures. Lower pressure boilers are subject to the same type of failures and while the appearance of fractures in thinner wall tubes may differ somewhat from those described, the similarity is such that they can be related.

For example, a 4-in. thin-walled tube failing from overheating is likely to rip open for a length of one and a half to three feet. However, the characteristic thinning to a knife-edge will be present at the point of initial fracture. This has been observed on thin wall tubes failing from other causes.

It may be acknowledged that the underlying cause of some failures may appear to be somewhat obscure; nevertheless in all but a few cases it should be possible by a thorough examination of the inside and outside of the failed tube, and of adjacent tubes, a study of the operating records and conditions and a careful analysis of all of these factors, to determine the basic cause of the trouble.

Advocates Drastic Curtailing of German Industry

Conquered Germany's electrical equipment industry, still grossly expanded despite 40 per cent destruction by Allied bombs, must be trimmed to normal peacetime production levels, in the opinion of Charles A. Powel, president of the American Institute of Electrical Engineers and newly appointed chief of the Electrical and Radio Branch of the Allied Control Commission.

"We know that the electrical equipment industry is vital to the waging of war," Mr. Powel asserted at a recent luncheon given in his honor by the Pittsburgh Chamber of Commerce, "yet it would be impracticable to blot out this industry from the Reich. Instead, we must assure that the industry henceforth produces only sufficient equipment to fill the peacetime needs of Germany and even then we must keep a careful check on that equipment to see that applications are in line with peacetime pursuits."

Plans Survey

Mr. Powel has first-hand knowledge of the expansion of Germany's electrical industry in pre-war years. He visited the Reich in 1938—a year before Britain and the Nazis went to war—and was amazed to find that production there probably exceeded that of the United States, the most electrically-minded country in the world.

"With this in mind," Mr. Powel said, "my first task under the Allied Control Commission will be to make a complete survey to determine just how greatly this expansion overshot the nation's normal needs. We will study the Reich's normal needs per year for a period as far back as, perhaps, 15 years. We will then study the extent and nature of existing facilities and recommend to the Commission a basis for permissible future activity of the industry."

Mr. Powel said his survey probably would take him to all parts of Germany where electrical equipment factories exist, including zones occupied by the British, French and Russians as well as the American occupied sector.

Warns Against Being Soft

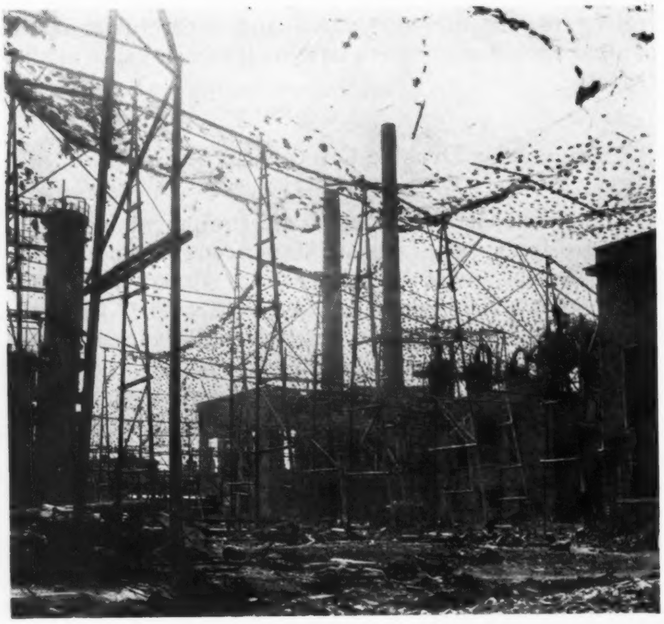
While advocating that Germany be permitted a certain amount of industry—manufacturing to which it is naturally suited, Mr. Powel pointed out the danger of the possibility that the Allied Nations may become "soft" after a short period of control in Germany.

"I am convinced that strict control over Germany must be maintained for two generations—40 to 50 years—so that the thinking of the people can be changed by education," he said. "If we keep going for five years and then grow 'soft', we will have lost the war.

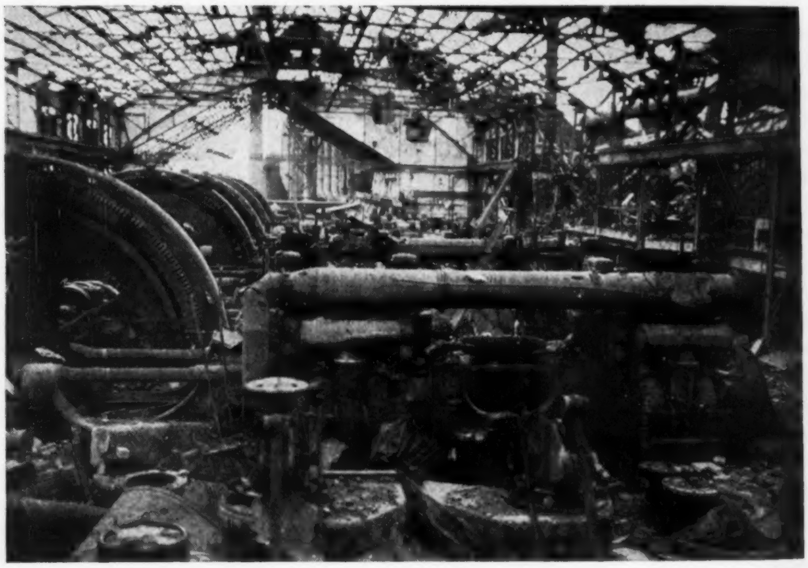
"Somewhere between the two extremes of making Germany a completely agrarian nation, as advocated by some, and allowing it any and all industries on the basis that they are essential to European economy, as advocated by others, there must lie a middle road. This middle road will permit the Germans a satisfactory balance between agriculture and industry and give them a decent standard of living.

Power Plants ihe
Allied Bombingve

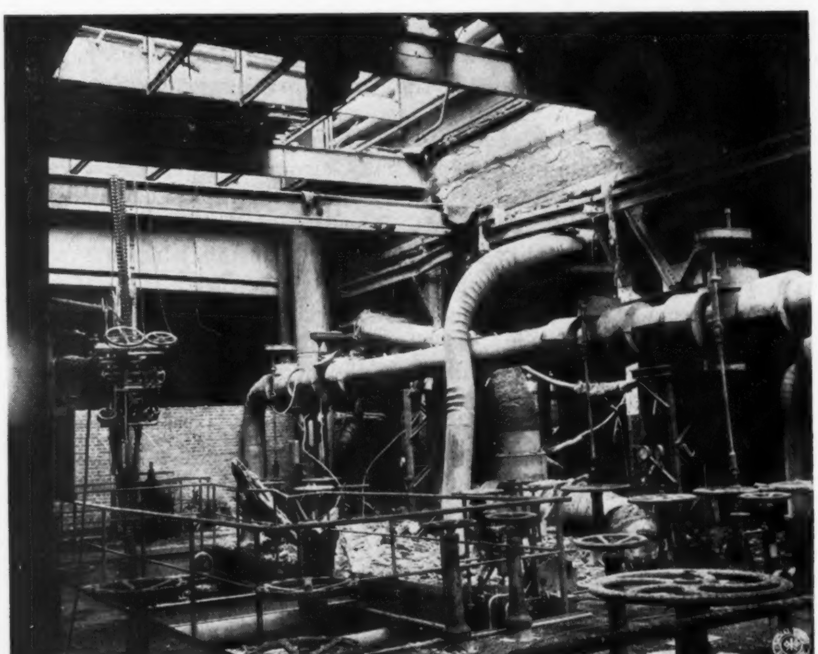
Photograghs by Signal Corps and released through the courtesy of the Bureau of Public Relations, U.S. War Department.



Bombed out power plant of an airplane fuel manufacturing plant at Bottrop, Germany. Note the camouflage netting.



Wrecked compressor plant at the gas works in Meunkirchen, Germany.



Wreckage from bombing of an industrial power plant at Duben, Germany.

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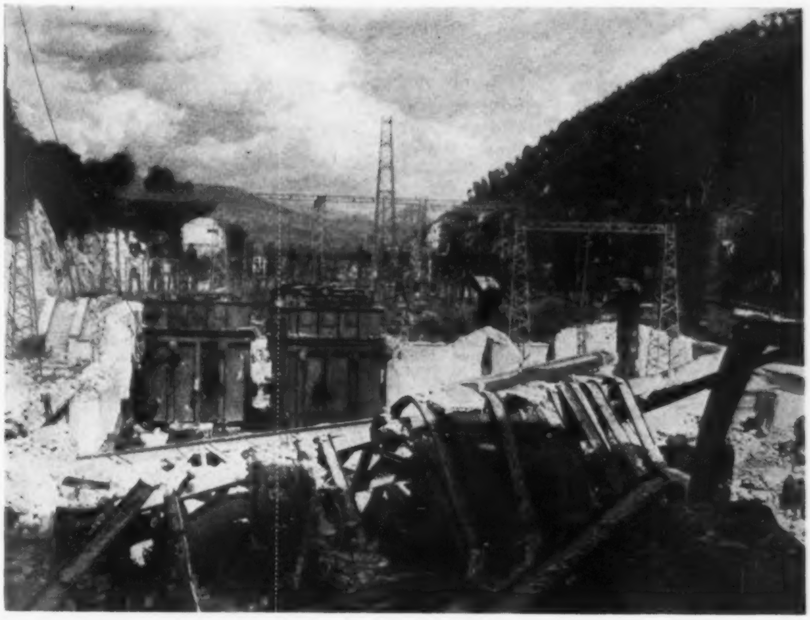
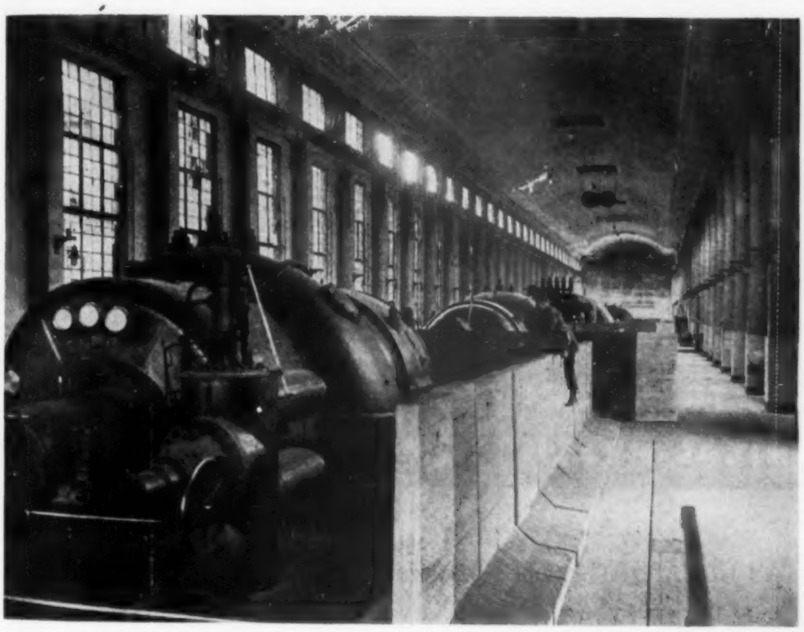
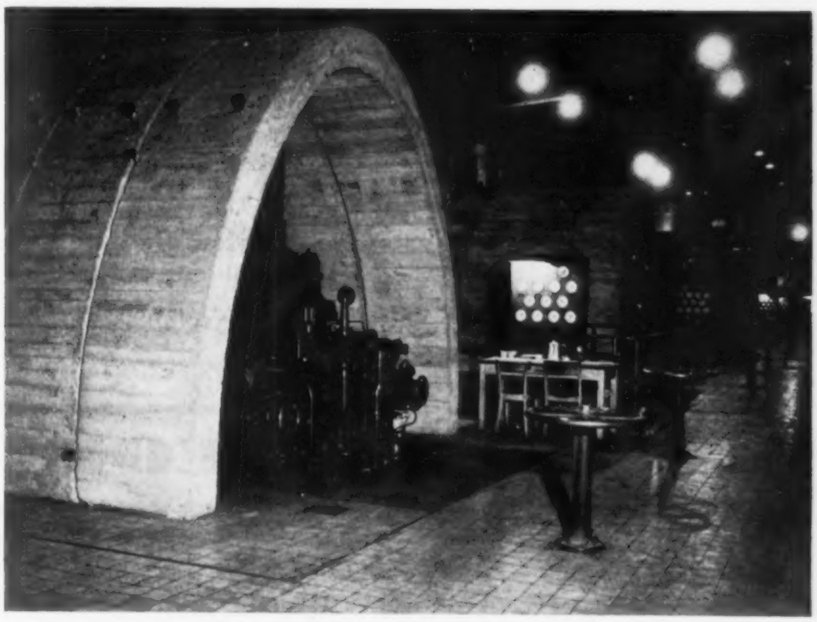


Transformers and switch yard of an Italian generating station wrecked by retreating Germans.



Turbine room of the Fortuna Power Station in the Cologne area, west of the Rhine which was captured without much damage. Note the concrete barriers around the machines.



Concrete protection over generators in a synthetic rubber plant near Huls, Germany, which was captured intact.

N

Operating Levels of Electric Utilities Expected to Remain Stable

Survey by the Federal Power Commission indicates expenditures for the balance of this year to about equal the rate for 1941-42, totaling 761 million dollars planned outlay. Estimates of 1945 total energy requirements exceed 227 billion kilowatt-hours and 39 million kilowatts demand, which are in excess of the figures for 1944.

THE ending of the war in Europe is likely to affect utility operations to only a limited extent, according to reports obtained by the Federal Power Commission. Only minor reductions in revenues are anticipated during the balance of 1945 and the early part of 1946.

Plant Expenditures

Gross additions, including renewals and replacements, planned by the electric utility industry are estimated at 529 million dollars. Expenditures for maintenance are estimated at 208 million and expenditures to increase depleted inventories of materials and supplies are placed at 24 million. Plant expenditures, while above the reduced rate for 1943 and 1944, are just about equal to the rate for the two-year period 1941–42. Maintenance expenses are expected to exceed the current rate to a relatively small extent. While such a limited increase in maintenance appears contrary to prevailing ideas as to a large backlog of deferred maintenance, the estimates are generally predicated on the assumption that the war against Japan will continue throughout the year and that available materials and labor will be limited.

A large proportion of the funds required for structures and equipment, maintenance materials and supplies will be available from cash on hand or from current operations. Of the planned outlay of 761 million by the electric utility industry, approximately 45 million will be obtained through the issuance of securities and the balance of 716 million, or 94 per cent of the total, will be available from cash.

ELECTRIC UTILITY EXPENDITURE SURVEY

Planned Outlays of Privately Owned and Municipally Owned Electric Utilities in the Twelve Months' Period Following the End of the European War

(Thousands of dollars)

Geographic Divisions	Revenues from Sales to Ultimate Consumers	Planned Outlays: Gross Additions to Utility Plant: Structures and Improvements	Equipment	Total	Maintenance	Increased Inventories of Materials and Supplies	Total Planned Outlays
UNITED STATES	*$3,105,530*	*$119,713*	*$409,099*	*$528,812*	*$207,972*	*$23,883*	*$760,667*
New England	233,720	9,148	28,450	37,598	15,997	2,205	55.800
Middle Atlantic	795,097	20,775	81,465	102,240	61,582	1,924	165,746
East North Central	763,598	24.791	99,965	124,756	51,575	8,895	185,226
West North Central	248,648	9,647	35,249	44,896	13,337	3,638	61,871
South Atlantic	357,230	12,597	57,455	70,052	23,460	3,090	96,602
East South Central	100,653	9,225	12,028	21,253	5,366	952	27,571
West South Central	199,434	14,478	32,075	46,553	13,472	1,025	61,050
Mountain	86,642	2,584	10,247	12,831	4,602	310	17,743
Pacific	320,508	16,468	52,165	68,633	18,581	1,844	89,058

A breakdown of these contemplated expenditures shows that about 87 per cent will be made by privately owned companies, which have 91 per cent of the revenues from sales to ultimate consumers, and 13 per cent by municipally owned utilities.

Comparison by geographic regions shows that of the total anticipated outlays the East North Central States will lead with over 185 million, followed by the Middle Atlantic States with over 165 million. None of the remaining regions reported planned outlays in excess of 100 million. The accompanying tabulation shows the geographical breakdown of these expected expenditures, with reference to plant additions, maintenance and increased inventories of materials and supplies; also anticipated revenues from sales to ultimate consumers.

Production and Peak Demands Hold Up

The report of energy sales for May, of 19,094,097,000 kwhr, was up about 673 million kilowatt-hours from April, and represented an increase of 2.3 per cent over that of May 1944. Peak demands aggregated over 37 million kilowatts which was 68,000 kw above that of April and 4.9 per cent over that of May 1944. Only in the Northwest and the Southwest were both the sales and demand less than last year, and the West Central region topped other sections of the country with increases in sales and demand of 9 and 14.1 per cent, respectively.

Latest available estimates for Class 1 systems of the current year's energy requirements indicate an excess of 227 billion kilowatt-hours and 39,646,781 kw demand. These figures, if attained, would represent an increase of 0.9 per cent for energy and 4.7 per cent for demand, as compared with 1944.

Dependable capacity, less required generating capacity reserves are reported as 40,179,122 kw, as of May 1, 1945, with scheduled additions increasing this total to 41,013,667 kw at the end of the current year. The total installed generating capacity of Class 1 systems (Nameplate rating) is given as 45,867,748 kw, as of May 1, 1945, which, on the basis of scheduled additions, is expected to increase to 46,606,338 kw at the year's end.

The foregoing figures are exclusive of federally owned and operated power plants.

STORAGE OF COAL

Results of some recent studies by engineers of the Bureau of Mines as contained in its annual report on "Research and Technologic Work on Coal," together with excerpts from a previous paper dealing with and comparing various methods of storing coal with special reference to degradation and prevention of spontaneous combustion. Special attention is given to the storage of sub-bituminous coal.

WITH a critical fuel situation facing industry for the current year in which estimated production is expected to fall below demand by some 37 million tons, coal users are being urged by the Solid Fuels Administration to purchase and store throughout the summer and early fall. This will involve much of the lower grade coal, some of which will require special precautions in storing. Therefore, the section on Storage of Coal from the recently issued Annual Report of "Research and Technologic Work on Coal" by the U. S. Bureau of Mines is most pertinent. This report says, in part and substance, as follows:

Field Surveys Made

Valuable new information on the action of coal in storage was gained through field surveys, laboratory investigations, questionnaires and exchange of ideas between representatives of the coal industry and Bureau engineers. Storing characteristics were studied of a number of coals mined in the Middle West, New Mexico, Arizona, Oklahoma, Arkansas and Washington; and additional studies were made of materials used for capping coal piles and the effect on their durability of the increased vapor pressure of high-moisture coals resulting from increased temperature.

Ten tons of lump sub-bituminous coal were stored for eight months inside a tight bin. It was leveled and covered with wrapping paper to prevent flow of air through the pile. During the storage period the moisture content changed from 23.6 to 21.1 per cent, the heating value from 13,270 to 13,060 Btu per lb (dry ash-free basis), the friability from 21 to 26 per cent and the B. of M. slacking index from 65 to 61 per cent. Visual inspection revealed little degradation. A maximum of 80 F in the pile was reached after 72 days and then gradually decreased to 65 F. During the 8-month period of storage, the outside temperature ranged from 18 to 100 F.

Some 13,300 tons of sub-bituminous slack from various mines in northern Colorado were stored in an open concrete pit from February to May 15. This was placed in 3-ft. layers and compacted by a tractor to a bulk density of 58 lb per cu ft, the total depth after compacting being about 15 ft. The results of temperature determinations are given in Table 1. The data show that practically all oxygen had been eliminated from the gases beneath the surface of the pile and that about a third of the oxygen from the air was absorbed by the coal and not liberated as products of oxidation. This, and earlier demonstrations, proved that sub-bituminous coal can be stored satisfactorily in open dry pits.

Spontaneous Heating in Storage

The relative tendencies of a number of coals to heat spontaneously in storage were measured in the Bureau of Mines laboratory by two different methods. In the first procedure, the characteristic oxidation rate of a 0–$^1/_4$-in. sample of the coal at 100 C in air was measured through use of a 50-lb rotary, steam-jacketed equipment. The second method involved drying a sample of 0–$^1/_4$ in. coal

TABLE 1—OBSERVED TEMPERATURE AND COMPOSITION OF GAS IN SUB-BITUMINOUS COAL STORED IN OPEN PIT AT BRUSH, COLO., JUNE 27, 1944*

Station Number	Temperatures in the Coal, deg F 3 ft	6 ft	9 ft	Composition of Gases at 4 ft CO_2	O_2	CO	N_2	Per cent Oxygen Absorbed†
1	130	98	85	13.5	0.2	0.0	86.2	32
2	132	108	92					
3	140	110	90	12.0	0.2	0.0	87.8	40
4	135	108	92					
5	132	110	95	12.1	0.3	0.0	87.6	40
6	125	100	82					
7	137	108	90	12.1	2.5	0.5	84.9	25
8	125	105	82					
9	122	97	78	7.7	4.3	0.0	88.0	42
10	125	105	85					
11	133	105	87	6.9	10.2	0.1	82.8	12
12	130	105	85					
13	128	103	87	12.4	0.2	0.0	87.4	39
14	133	110	90					
15	128	105	85	12.4	0.8	0.3	86.5	34
16	140	110	87					
17	132	108	85	11.3	0.4	0.0	88.3	44
18	135	112	82					
19	137	110	85	14.1	0.2	0.0	85.7	30
20	132	100	83					
Average	132	106	86	11.5	1.9	0.1	86.4	33
Average entire pit, 108 F								

* Observations made at 20 stations, 30 ft from walls of pit and 40 ft apart. Length of pit is 423 ft, width 100 ft, and coal depth about 15 ft. The pit contains about 13,300 tons of coal placed in approximately 3-ft compacted layers during the period from February to May 15, 1944. Top surface of pit is level and compacted to give total average bulk density of 58 lb per cu ft.

† Oxygen absorbed,

$$\text{Per cent} = 100 \times \frac{\dfrac{N_2}{0.809} - \left(N_2 + CO_2 + O_2 + \right)\dfrac{CO_2}{2}}{\dfrac{N_2}{0.809} - N_2}$$, Based on ultimate CO_2 = 19.1 per cent

at 100 C in an inert atmosphere and then placing the dried coal in an adiabatic-type calorimeter of 110 lb capacity, heating to the temperature at which it is desirable to start the test and then passing oxygen up through the apparatus at such a rate that an atmosphere containing 85 per cent or more oxygen is maintained in contact with the coal. The rise in temperature of the coal is a measure of the tendency to heat spontaneously in storage.

Results of tests by both methods on several coals are contained in Table 2. Agreement between the two types of tests was good for the high-volatile *A* coals and seemed fairly satisfactory for the sub-bituminous coals and lignite. The latter are more likely to cause trouble through spontaneous heating during storage than the high-volatile *A* coals, and because of their high reaction

TABLE 2—COMPARISON OF TENDENCIES OF VARIOUS COALS TO HEAT SPONTANEOUSLY DURING STORAGE

Coal and Source	Rank	Characteristic Oxidation Rate at 100 C Ra (X = 1)*	Ratio to Pittsburgh-bed Coal	Self-heating Rate at 100 C, deg C per Hr	Ratio to Pittsburgh-bed Coal	Average Ratio to Pittsburgh-bed Coal
Pittsburgh bed, Warden mine, Allegheny County, Pa.	High-volatile *A*	0.13	1.0	1.83	1.0	1.0
Eagle bed (prospect hole), Kanawha County, W. Va.	High-volatile *A*	0.12	0.9	1.12	0.6	0.8
Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky.	High-volatile *A*	0.27	2.1	4.00	2.2	2.2
Monarch bed, Sheridan County, Wyo.	Sub-bituminous *B*	3.30†	45.0‡	143.00	78.0	62.0
Healy River coal, Alaska	Sub-bituminous *C*	0.57†	7.7‡	22.50	12.3	10.0
Velva mine lignite, Ward County, N. Dak.	Lignite	13.10†	177.0‡	93.00	51.0	144.0

* Characteristic oxidation rate, the percentage of oxygen consumed per day at 100 C in air after the coal has consumed 1 per cent of its dry, mineral-matter-free weight of oxygen.

† The rate of oxidation, percentage of oxygen consumed per day at 100 C in air after the coal has consumed 5 per cent of its dry, mineral-matter-free weight of oxygen. For Pittsburgh bed, Warden mine, this value is 0.074 per cent per day.

‡ Ratio of the oxidation rates after the coal has consumed 5 per cent of its dry, mineral-matter-free weight of oxygen compared to Pittsburgh bed, Warden mine.

rates, it is difficult to measure accurately their tendencies to heat.

The influence of storage on caking and coking properties of coal were also investigated.

Methods of Storage

The report makes reference to a previous publication of the Bureau of Mines[1] in which various methods of storing coal are reviewed and compared. Excerpts from this are reproduced in the following in view of the present urge to store coal:

"Under-water storage will prevent access of air, hence all spontaneous heating; and it does not harm the coal appreciably except to make it very wet. However, from a practical standpoint, it may give more trouble than coal stored dry.

"If coal is stored in an open pit in the earth, segregation of the coal sizes should be avoided in placing the coal in the pit and the level should not be higher than the top of the pit. Air has access to the top and to some extent around the sides; hence covering with a layer of 10 to 12 in. of very fine coal will help to keep out the air. Coals that slack readily, such as sub-bituminous, will slack for some inches at the top. If, with some coals, undesirable heating does occur, the pit can always be flooded.

"When storing slack coal in layers 2 to 3 ft in thickness on hard or compacted earth, it is important that the base be free from all rubbish or vegetation, and reasonable drainage should be provided; without resorting to tile or ashes which will tend to permit access of air to the bottom of the pile. Segregation of coal sizes should be compacted, preferably with a caterpillar tractor, if available; otherwise a truck may be employed. The sides of the pile should be inclined about 35 deg and be carefully compacted. Any reasonable height up to 50 ft is permissible. Most eastern coals may be stored satisfactorily by this method, but further precautions must be taken with coals that fire readily.

"Where slack coal is merely piled on open ground, letting the larger pieces segregate to the sides as it falls, trouble may be expected unless the piles are very small. Hence, such piles should not be over about 6 ft high.

"Coal that is covered so that there is no air flow into or out of the pile will not give heating trouble. Coverings that have been employed successfully (other than coal dust) include cut-back asphalts, asphalt emulsion, road tar, etc. They will also prevent a coal-dust nuisance, windage loss, and moisture penetration.

"When storing in bins, bunkers and silos, all foreign material should be removed, segregation of sizes should be avoided, as well as access of air, and care should be taken to guard against external sources of heat.

"Most coals stored in a bunker or bin that is really air-tight will not catch fire from air that reaches it at the top only. Air leakage can often be detected with an ordinary candle flame.

"If the coal is sized there is less likelihood of heating. In general, the higher rank coals with the fines screened out may be stored without incurring much danger of heating."

[1] The Storage of Coal," by J. F. Barkley.

EQUIPMENT SALES

as reported by equipment manufacturers to the Department of Commerce, Bureau of the Census

Boiler Sales

Stationary Power Boilers

	1945 Water Tube		1944 Water Tube		1945 Fire Tube		1944 Fire Tube	
	No.	Sq Ft*	No.	Sq Ft*	No.	Sq Ft	No.	Sq Ft
Jan.	105	656,593	36	226,537	50	60,710	24	31,701
Feb.	103	496,586	39	256,942	75	99,815	28	43,341
Mar.	135	784,407	47	229,121	77	87,266	44	53,893
Apr.	85	422,213	80	454,175	78	99,154	50	68,430
May	125	812,989	74	392,347	81	83,285	49	66,722
Jan.–May incl.	553	3,172,788	276	1,559,122	361	430,230	195	264,087

* Includes water wall heating surface.

Total steam generating capacity of water tube boilers sold in the period Jan. to May (incl.), 1945, 31,754,000 lb per hr; in 1944, 13,136,000 lb per hr.

Marine Boiler Sales

	1945 Water Tube		1944 Water Tube		1945 Scotch		1944 Scotch	
	No.	Sq Ft*	No.	Sq Ft*	No.	Sq Ft	No.	Sq Ft
Jan.	363	1,542,274	49	273,879	6	1,073	—	—
Feb.	34	178,726	96	507,658	5	1,186	30	9,000
Mar.	69	240,004	70	226,166	10	7,685	38	9,700
Apr.	16	65,252	44	209,906	4	2,126	44	14,405
May	26	110,126	94	443,130	2	526	37	11,100
Jan.–May incl.	508	2,136,382	353	1,660,739	27	12,596	149	44,205

* Includes water wall heating surface.

Total steam generating capacity of water tube boilers sold in the period Jan. to May (incl.), 1945, 20,240,000 lb per hr; in 1944, 21,902,000 lb per hr.

†Mechanical Stoker Sales

	1945 Water Tube		1944 Water Tube		1945 Fire Tube		1944 Fire Tube	
	No.	Hp	No.	Hp	No.	Hp	No.	Hp
Jan.	43	19,423	35	13,982	185	24,899	149	20,961
Feb.	‡57	22,510	34	18,437	162	20,565	158	22,655
Mar.	108	39,801	125	52,547	236	32,447	457	66,500
Apr.	59	21,604	194	79,008	198	27,438	640	92,338
May	102	40,977	248	99,928	245	33,072	865	123,155
Jan.–May incl.	369	144,315	636	263,902	1,026	138,421	2,269	325,609

† Capacity over 300 lb of coal per hour. ‡ Revised.

AMERICA'S FUTURE OIL SUPPLIES

Points stressed by Dr. Wilson are that known oil reserves are still high; that much can be expected from technological developments in meeting future demands for petroleum products; that the day of burning fuel oil in direct price competition with coal is about over; and that demands of the Pacific warfare will defer until after V-J Day any increase in allotments of oil for domestic heating.

ADDRESSING the American Society of Mechanical Engineers at Chicago on June 19, Dr. Robert E. Wilson, Chairman of the Board, Standard Oil Company of Indiana, took occasion to correct some prevailing misunderstandings concerning the future supply of petroleum. While it is true, he explained, that the number of years' supply of proven crude reserves has declined, this is only because the current rate of consumption has increased so rapidly; but actually the known reserves at the end of 1944 had reached a new high. In other words, the yardstick has grown. Twenty-five years ago, when the early exhaustion of crude oil was predicted, the total known reserves were then only 6½ billion barrels; but since then we have produced 25 billion barrels and still have over 20 billion barrels of proven reserves.

Technological Advances

Technology has played a large part in keeping up the supply of petroleum. Where once 70 to 80 per cent of the oil was left in the ground, at present, usually not more than 30 to 40 per cent remains after the pumps have been pulled. However, the heavy oils are being converted into lighter and more valuable products and *the day of burning fuel oil in direct price competition with coal is about over*, in Dr. Taylor's opinion. Availability of higher octane gasolines will lead to the development and widespread use of more efficient engines and this will cut down the amount of fuel they will need.

Nevertheless, despite improvements in methods of locating and producing oil, the returns per unit of effort are diminishing, Dr. Wilson acknowledged. But the petroleum industry has no fear of actual exhaustion of its raw material, because the lighter petroleum products can be made from natural gas, coal and oil shale. Just over the horizon, he said, is the making of gasoline from natural gas by the Fischer-Tropsch process. The cost should not be much greater than at present, and large quantities of natural gas are available, notwithstanding the fact that much of the supply has been earmarked for public utility use.

Until their plants were destroyed by Allied bombing, after the destruction of the large refineries in Romania, the Germans had been obtaining the greater part of their gasoline requirements from lignite and coal. If the need arises we can do likewise at a cost of probably not more than five cents a gallon higher than at present, as there are abundant tar sands, mainly in Canada, and vast oil shale deposits in our western states.[1]

Foreign Sources Can Relieve the Situation

But in order to delay the time of turning to these new sources of oil, with the accompanying higher prices for the products, Dr. Taylor suggested that greater reliance be placed on foreign sources of petroleum. A country that has only about 35 per cent of the known petroleum reserves cannot expect to continue indefinitely to furnish 65 per cent of the world's oil requirements, as the United States has been doing. Oil from the rich fields of the Middle East should be expected to supply an increasing proportion of Europe's needs. This would make available a greater proportion of the Venezuelan oil supply for the western hemisphere. "The sound thing to do," he emphasized, "would be to keep enough oil coming into this country so that there will be no lack for transportation and industrial needs, but not so much as to prevent domestic crude prices from being high enough to keep our geologists and drillers hunting for oil and our chemical engineers interested in the development of substitute sources of oil. As this war has abundantly proved, only a strong and vigorous domestic industry can be relied upon in a real war emergency."

Effect of Increased Pacific Warfare

At present the oil industry in this country is producing and refining over a million barrels per day in excess of that which it produced in 1942. While fighting was in progress both in Europe and in the Pacific, the armed forces consumed all of this increase and an additional 700,000 bbl per day which was squeezed from the civilian economy.

The end of fighting in Europe made possible the recent increase of 50 per cent in allotment of gasoline to passenger car users, but it is anticipated that tremendous quantities will soon be flowing across the Pacific. Furthermore, the type of fighting that has developed against the Japanese has necessitated use of flame-throwers to dislodge the enemy from caves and other hide-outs, and these consume considerable quantities of gasoline. It was Dr. Taylor's opinion that these military demands would not result in a reduction of present civilian allotments; also, in the first post-war year the shortage of cars would likely produce a slump in gasoline demands as compared with pre-war levels. He did believe, however, that the stepping up in the tempo of the war with Japan would involve such an increase in fuel oil demand for naval vessels and transports that home owners who are dependent on oil for heating could expect no substantial increase in their allotments of distillate fuels before V-J Day.

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1 The U. S. Bureau, under a special appropriation by Congress, is now engaged in construction of pilot plants in the west for such development.

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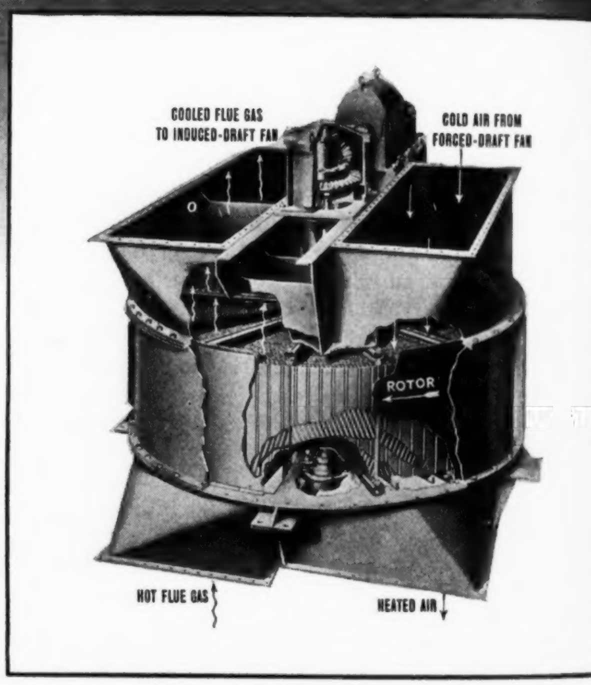

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Pumping Features of the Big Inch Pipe Lines

SPEAKING before the Michigan Section of the A.I.E.E., **Merritt A. Hyde** Petroleum Engineer of Westinghouse Electric Corporation, cited some interesting features relative to the "Big Inch" Pipe Lines and their pumping installations.

It will be recalled that these lines were constructed as an emergency war measure to bring much-needed oil from the Texas fields to the Eastern Seaboard. The "Big Inch" Line, two feet in diameter, extends from Longview, Tex., to Phoenixville, Pa., a distance of 1264 miles, and there forks into two 20-in. lines one of which supplies the Philadelphia area and the other the New York area. The total length is approximately 1400 miles through varying terrain, ranging from the Mississippi bottoms to the ridges of the Alleghenies where the highest point crossed is 2900 ft. When operating at capacity this line handles a column of more than 4 million barrels of crude oil, weighing 600,000 tons, at a speed of $4^1/_4$ mph. This involves a pumping load of nearly 100,000 hp. The delivery is 320,000 bbl per day.

The second line, known as the "Little Big Inch," is 20 in. in diameter and delivers 225,000 bbl per day of gasoline, or other petroleum products, from the refineries of the Gulf Coast to Linden, N. J., a distance of 1600 miles. On a monthly basis, this represented a little over half the high-octane gasoline requirements of our air forces in Europe.

The "Little Big Inch" Line, drawing its products from eleven refineries in the Gulf Coast area, runs 350 miles from Beaumont, Tex., to Little Rock, Ark., where it joins the right-of-way of the 24-in. line and parallels it from there to the East. This permits pumping for both lines to be at the same sites and thereby effected considerable savings in installation costs, operating labor and power procurement.

All pumping is performed by motor-driven centrifugal pumps, of which there are 80 units of 1500 hp each in 26 stations located at intervals averaging 52 miles; generally with three units per station. The actual distances between stations vary from 31 to 78 miles. The total installed capacity applied to main line pumping is approximately 120,000 hp, with an additional 10,000 hp covering spare and auxiliary units. Power is supplied by sixteen different utility companies, many of which had to construct extensions to their lines in order to serve the pumping stations. Service voltages range from 22,000 to 110,000 volts which are stepped down to 2300 volts.

Allowable Pressure Dictated Number of Stations

Employment of a large number of stations was dictated by the necessity of limiting station delivery pressure to a value that develops a piping stress within the allowable limit. For instance, considering the section of the line between Longview and Phoenixville, if the pumping capacity had all been installed at the former site, delivering 300,000 bbl per day through 1264 mi of 24-in. pipe, with a pressure drop per mile of 12 psi and against a static head of 50 psi, due to the net difference in the two station elevations, the Longview station would have had to operate with a discharge pressure of 15,250 psi. But by employing 26 pumping stations along the line, the average net pressure developed at each station becomes about 635 psi, or allowing for a suction pressure at each station of 50 psi, the station discharge pressure would be 685 psi. In actual operation, capacity flow is somewhat higher than the 300,000 bbl per day nominal rating and the net input pressure at each station is in the neighborhood of 675 psi. Adding the suction pressure the maximum pressure becomes 725 psi, which is practical from the standpoint of pipe design.

The pumps are single stage, each rated 8750 gpm against a 648-ft head at 1780 rpm. Each is driven by a squirrel-cage induction motor, with the motor room separated from the pump room by a fire wall with no communicating doorways, so as to reduce fire hazard. All push-button controls in the pump room for starting and stopping the units are of explosion-proof type, as are also the pressure-protective relays. This was deemed necessary as the pump room, because of drainage from pump glands and pump-casing venting, as well as any abnormal leakage, renders it a hazardous location.

Pump room of typical Big Inch Pumping Station

Left—Wreckage of I. G. Farbenindustrie oil plant at Ludwigshafen (an official War Dept. photograph)

Secrets of German Synthetic Oil Production Revealed

Following repeated and devastating bombings by the RAF and American flyers, many of the German synthetic liquid fuel plants were in the process of being moved underground when Nazi resistance finally collapsed. So reports Dr. W. C. Schroeder of the U. S. Bureau of Mines who headed a group of twenty-two experts sent overseas to study the bomb-scattered remnants of these plants, to collect records and to interrogate plant personnel.

The German synthetic liquid fuel plants kept the Wehrmacht and the Luftwaffe operating far longer than many thought possible. However, their total production, estimated at about 4 million tons of oil per year at the peak, was reduced to below 5 per cent of that amount despite the efforts of repair crews, estimated up to 20,000 men at times for a single large plant. A perusal of the production curves showed a sharp downward slope in 1943, except at such times as bad weather grounded the allied bombers.

Confidential Records Hidden

According to Dr. Schroeder, the Allied bombers did their job so thoroughly that the group learned very little from the remains of the plants themselves, but much information was gained through tracing down secret records and confidential documents hidden in farm houses, vineyards, under haystacks and in an ancient moated castle, and in cross-examining sometimes reluctant witnesses.

At Wesseling, site of a large hydrogenation plant, a German engineer finally admitted that he had compiled a complete story of the plant and buried the manuscript. This illustrated record of 250 pages gave the investigators their best idea of this type of operation, disclosing one German dehydrogenation process for making aviation gasoline. These plants were operated at extremely high pressures (several hundred atmospheres) and discovery of new catalysts had permitted the conversion of middle oil fractions to high-octane gasoline in a single step.

Near Reelkirchen, an artillery officer had noticed a German boy playing with a stack of blueprints. Suspecting their importance, he learned that these and many other documents had been hidden in a farmhouse. An intensive search of the area yielded many boxes of records, from which the oil mission investigators later found the answers to many questions dealing with recent German research upon the gas synthesis method of producing liquid fuels and lubricants from coal. A number of shale oil plants were also examined.

Information thus collected will later be made available to American industry and will also be employed in connection with the Bureau of Mines synthetic liquid fuels research program.

Post-War Power Development in China

Writing in May *Journal* of the Chinese Institute of Engineers, K. P. Pao, General Manager of the Ming Kiang Electricity Works and a member of the National Resources Commission of China, who is now on a special mission to the United States, reviews the outlook for post-war power development in China. This involves a program for the installation of some two million kilowatts of generating capacity. He says in part:

"As steam plants usually require less time to construct and involve smaller first costs, it seems logical to build more steam plants first, immediately after the conclusion of the war, to meet the urgent need of industrial rehabilitation. But in some parts of the country where the coal resources are poor and favorable hydroelectric power sites are available, it will be more economical to construct hydro stations immediately.

"In the first five years of development, about two-thirds of the installed capacity will be steam and one-third hydro. In the second period of development, however, when the demand for power will not be so urgent and the conservation of national resources should be given more consideration, the hydro development will assume a higher proportion.

"Before the war, fairly high volatile steaming coals were used in most power plants, and long distances of transportation were sometimes necessary. National economy requires the saving of transportation facilities and the conservation of suitable coals for industrial and metallurgical purposes. So, after the war, more attention should be given to the utilization of locally available low-grade fuels, such as high-ash coals, semi-anthracite and lignite. Mine-mouth power stations will be built wherever economically feasible.

"Besides the unification of frequency and voltages, the work of standardization should be further extended. Tentative standards for steam conditions, sizes of generating units, transmission and distribution equipment, etc., have been drafted.

"The magnitude of the power supply in the first stage of development will not justify long transmission lines in all regions; but in the industrial regions, it is considered more economical to concentrate the power supply in a few economical stations where favorable hydro sites can be developed or cheap fuels can be utilized, and to transmit the energy to the load centers by short-distance transmission lines of 50 to 100 miles. About fifteen such networks have been planned."

In 1936 the total installed capacity of China's 460 public utility power plants and 158 larger industrial power plants reached 876,813 kw; but the war has dealt a heavy blow, as most of the larger power stations were either destroyed or occupied by the Japs. The stations left in free China were inadequate to meet the urgent demand for power. However, the capacity of these stations has since been increased from 15,000 kw to about 70,000 or 80,000 kw.